MINERALOGY AND SPECTROSCOPY OF MOUNT ETNA LAVA FLOWS AS AN ANALOGUE TO VENUS.

Gabriel L. Eggers[1], Justin Filiberto[2], Piero D'Incecco[3], Nicola Mari[4], Giovanni Leone[5], Carmelo Monaco[6], Iván Lopéz[7], Alexey Martynov[8], and Pavel Pisarenko[8]. [1]Lunar and Planetary Institute, USRA, Houston, TX 77058 (geggers@lpi.usra.edu), [2]Astromaterials Research and Exploration Science (ARES) Division, X13, NASA Johnson Space Center, Houston, TX, 77058, [3]Dipartimento di Ingegneria e Geologia (INGEO), Università d'Annunzio, 65127 Pescara, Italy, and [4]Department of Earth and Environmental Sciences, University of Pavia, 27100 Pavia, Italy, [5]Instituto de Investigación en Astronomía y Ciencias Planetarias, Universidad de Atacama, 15300 Copiapó, Chile, [6]Dipartimento di Scienze Biologiche, Geologiche e Ambientale, Università di Catania, 95129 Catania, Italy, [7]Área de Geología, Universidad Rey Juan Carlos, 28933 Madrid, Spain, [8]Lavochkin Association, 141400 Moscow, Russia.

Introduction: Reports of geologically recent volcanism at Venus [1–3] raise the question of whether Venus is actively resurfacing. Observing the venusian surface is difficult due to the planet's thick, relatively opaque atmosphere, but emission from the surface is detectable via a few atmospheric windows in the near-infrared (NIR) around 1 μm [4]. Spectroscopy of rocks at these wavelengths varies due to its primary composition and the presence of secondary weathering products [2, 5, 6]. If degree of alteration can be tied to the spectroscopic response, then the weathering of the venusian surface can reveal its age and extent of recent volcanism [2, 7].

Mount Etna on Earth is a potential analogue to Venus that can aid our understanding. The composite volcano is currently active and exhibits a progression of dated lava flows with a range of textures (ʻaʻā versus pāhoehoe flows) and degrees of alteration [8]. While not a perfect analogue due to differing weathering environments, Mount Etna represents a natural age progression of altered basaltic rock [8] that can provide a useful comparison to volcanic structures on Venus. Here we will determine if spectroscopy can determine the alteration state of these flows as a proxy for their age.

Future missions to Venus such as VERITAS, EnVision, and DAVINCI will observe the surface in NIR emissivity. Kirchhoff's Law holds that $e = 1-r$, where e is the emissivity and r is the reflectance. NIR emissivity can be reliably calculated from reflectance measurements of rocks [9], so laboratory reflectance spectroscopy is useful to rapidly test potential Venus analogue materials.

Samples & Methods: The analogue samples were collected from ten different ʻaʻā lava flows at Mount Etna ranging from basalt to basaltic andesite in composition. Sampling locations are given in Figure 1. The samples represent a natural age progression of ~ 400 years with most of the flows dating to between 1610 and 2001. Two outliers are sample ET9, which dates to 2500 ± 30 BCE, and sample ET4, which is of unknown age.

We measured visible/near-infrared (VNIR) reflectances of the Mount Etna samples in the 0.5–2.5 μm range using a Spectral Evolution OreXpress spectrometer with its contact probe attachment (phase angle of $\sim 30°$). A standard white Spectralon plate was used as a reference. Measurements were taken on the weathered surface and fresh interior of each sample at multiple points to characterize its general spectral behavior.

Figure 1: Mount Etna with lava flow sampling locations marked along with the year of eruption.

Results: A representative subset of full-resolution spectra from the weathered surfaces of each sample are shown in Figure 2A. While spectra from the fresh interiors of the samples revealed a general basaltic character with an absorption band centered on 1 μm, these weathered spectra show the influence of iron oxides by the disappearance of this band. The spectra of the youngest samples retain a hint of this feature in the concavity of the curve in the vicinity of 1 μm, but for the older samples this concavity generally flattens and then inverts as iron oxides begin to dominate the spectral character.

The second trend observed is increased reflectance with sample age. The youngest samples (< 50 years) tend to have reflectances of 5–10% at 1 μm and longer wavelengths while the older samples (~ 200–400 years) tend to have greater reflectances of 13–18% in the same range. However, the trend is not universal—the weathered surface of ET8 produces inconsistent spectra and the oldest sample ET9 yields reflectances in the lower register—but on first order it holds.

Figure 2B shows these full-resolution spectra of weathered surfaces filtered to the six wavelengths of the Venus Emissivity Mapper (VEM) [4]. While the finer mineralogical details are mostly lost, the general age pro-

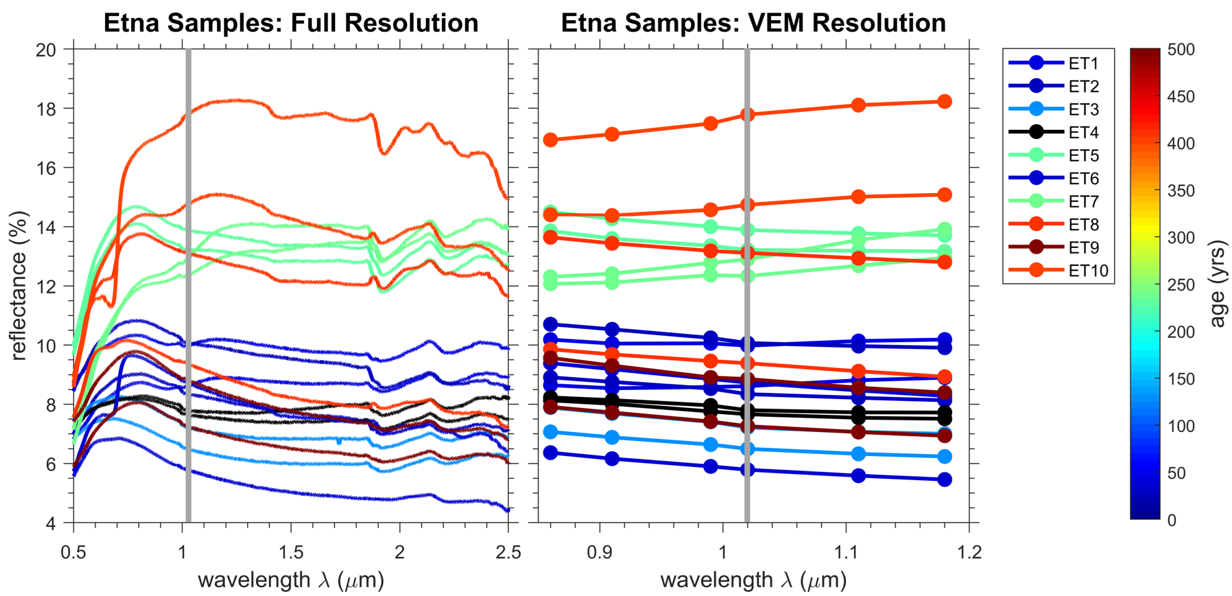

Figure 2: Full (left) and VEM-filtered (right) resolution spectra of the weathered surfaces of the Mount Etna samples. Spectra are color-coded by the age of the lava flow with blues being younger and reds being older (capped at 500 years). Unknown ages are in black. The vertical grey line denotes 1.02 μm, the band at which VIRTIS observed [1].

gression of younger samples being darker and older samples being brighter is apparent.

Implications: To the first order, these results demonstrate that spectroscopy can determine alteration state as a proxy for the age of a sample, as has been suggested based on laboratory experiments [2, 7]. For example, based on the observed trend in these Mount Etna samples, the lava flow of unknown age from which ET4 was sampled likely erupted 50–100 years ago. On Venus, recent volcanism has been argued at Idunn Mons in Imdr Regio due to its (albeit model-dependant) anomalously high emissivity of 0.85–0.9 at 1.02 μm [1, 3]. Per Kirchhoff's Law, this converts to a reflectance of 0.1–0.15, which according to the Mount Etna trend corresponds to an age on the younger end of 100s of years. This estimate is significantly younger than the 0.25–2.5 Ma age range estimated by [1] but older than the several years estimate by [2], comparable to the estimate for a fully crystalline, pyroxene-dominated basalt [10].

However, the progression observed with the Mount Etna samples is not simple and should not be over interpreted. Furthermore, the weathering environment of the venusian surface is drastically different from Mount Etna, so the rate and nature of alteration likely differs. Still, alteration has measurable impact on the spectra of natural basaltic rock and can be exploited to gauge recent volcanic activity on Venus. Thus, future missions such as VERITAS or EnVision should prioritize observation of possibly active volcanoes on Venus such as Idunn Mons.

Future Directions: To further investigate this progression, we will confirm the mineralogy using Raman spectroscopy at the same spots where VNIR measurements were taken to better understand the mineral constituents producing the spectra. Select samples will also be cut and sectioned perpendicular to the surface. Using scanning electron microscopy, we will measure alteration rind thicknesses and analyze detailed mineralogical and compositional changes to determine alteration rates.

Furthermore, the spectra of weathered rock is determined not only by the presence of alteration products but also by the specific chemistry and mineralogy of the primary rock. These measurements will aid understanding of how initial basalt chemistry effects the spectroscopy of its weathered products, but in preparation for future Venus observations, more work should also be done on the effects of weathering on the spectroscopy of other igneous primary materials.

Acknowledgements: This work was supported by NASA SSW grant 80NSSC17K0766.

References: **[1]** Smrekar, S. E. et al. (2010). *Science* 328, 605–608. **[2]** Filiberto, J. et al. (2020). *Sci. Adv.* 6. **[3]** D'Inecco, P. et al. (2021). *Planet. Sci. J.* 2. **[4]** Helbert, J. et al. (2021). *AGU Fall Meeting*. Abstract: P34B-06. **[5]** Gilmore, M. et al. (2017). *Space Sci. Rev.* 212, 1511–1540. **[6]** Dyar, M. D. et al. (2020). *Geophys. Res. Lett.* 47. **[7]** Fegley, B. et al. (1995). *Icarus* 118, 373–383. **[8]** Branca, S. et al. (2021). *Ital. J. Geosci.* 130, 265–291. **[9]** Treiman, A. et al. (2021). *Planet. Sci. J.* 2. **[10]** Cutler, K. S. et al. (2020). *Planet. Sci. J.* 1.